

# The influence of sea ice on Arctic low cloud properties and radiative effects

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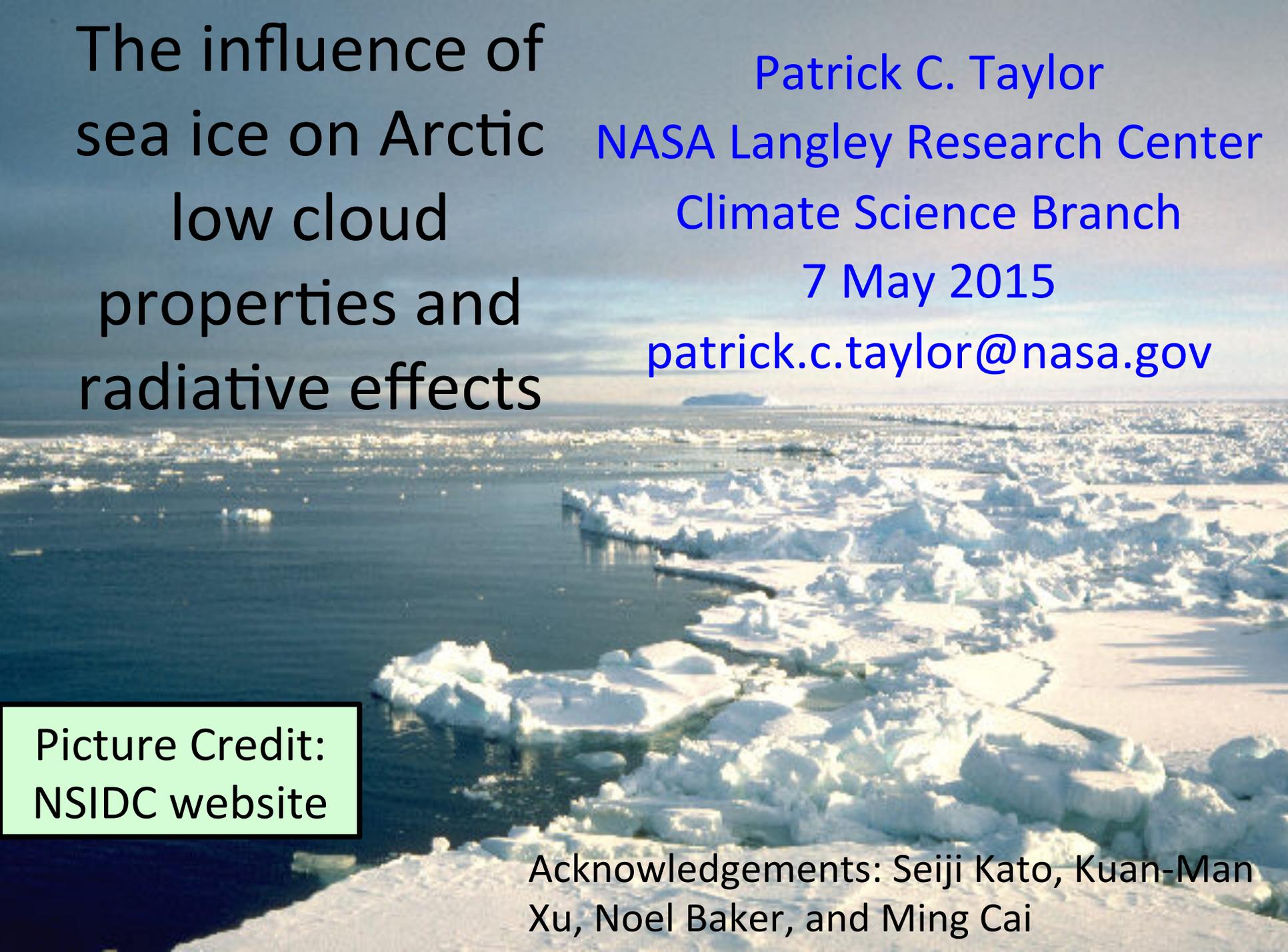
Climate Science Branch

7 May 2015

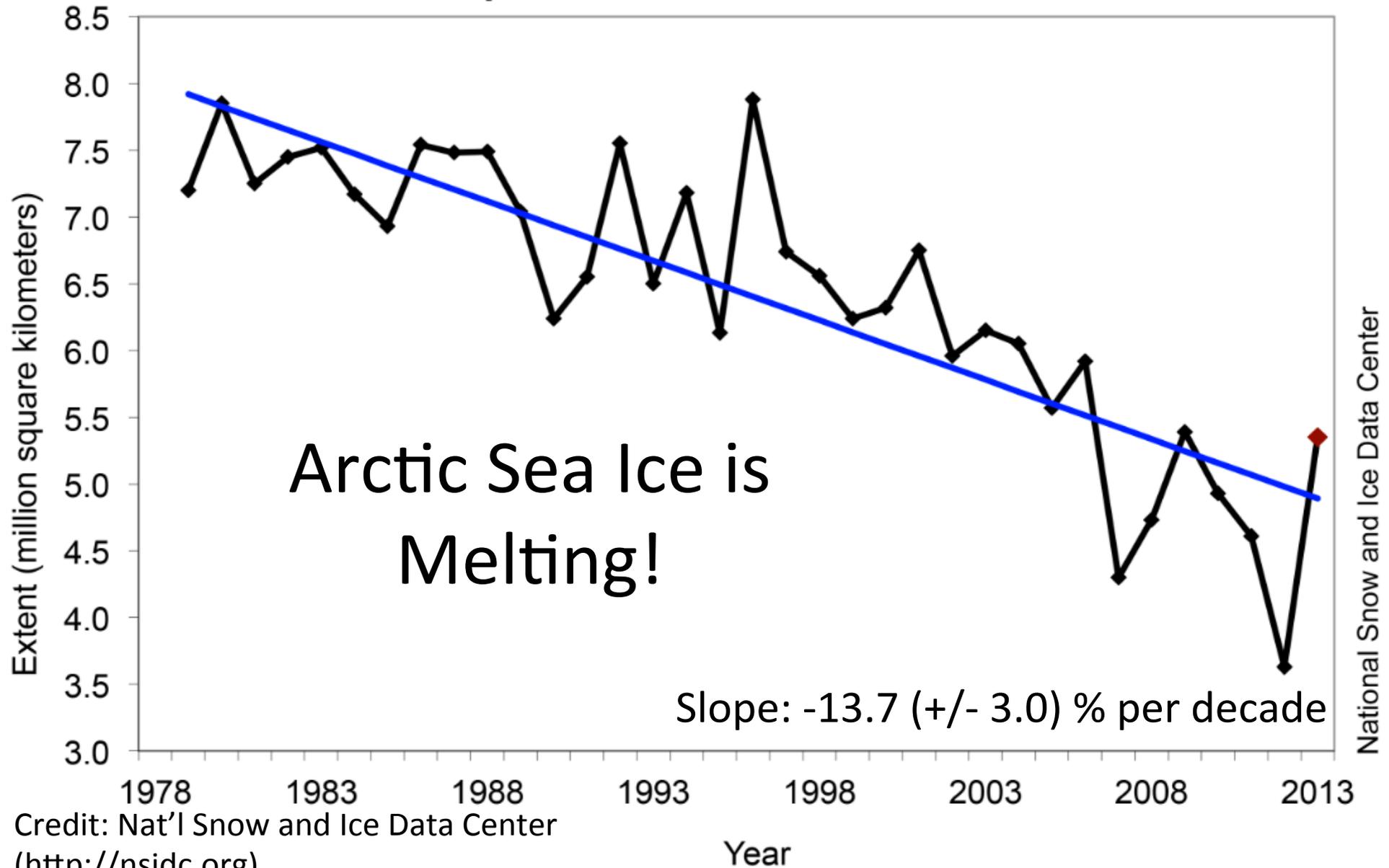
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Picture Credit:  
NSIDC website

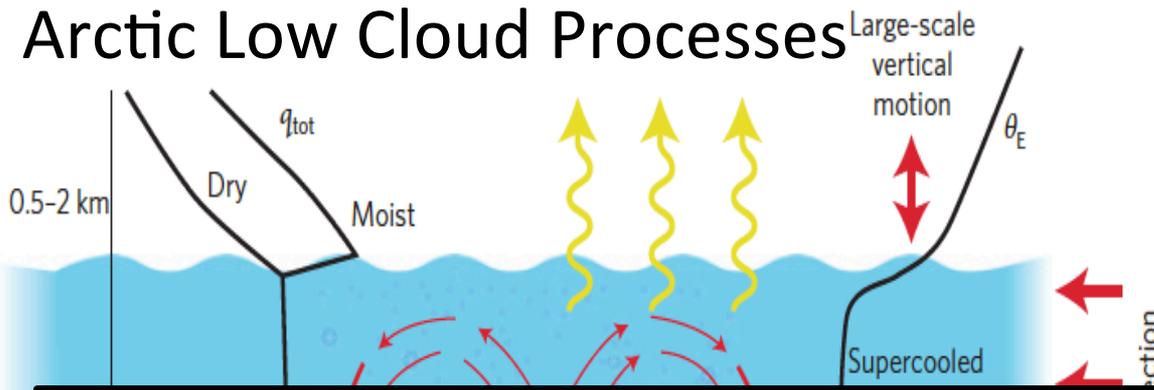
Acknowledgements: Seiji Kato, Kuan-Man Xu, Noel Baker, and Ming Cai



# Average Monthly Arctic Sea Ice Extent September 1979 - 2013



# Arctic Low Cloud Processes



## Radiative Cooling

- Drives buoyant production of turbulence
- Forces direct condensation within inversion layer
- Requires minimum amount of cloud liquid water

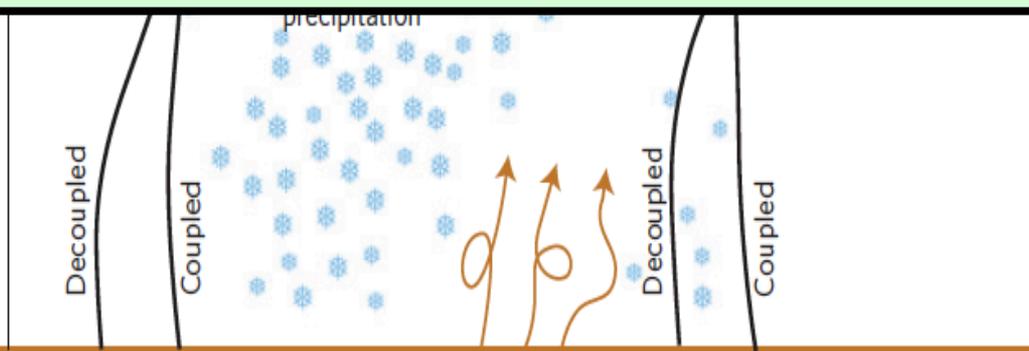
## Microphysics

- Liquid forms in updrafts and sometimes within the

## Science Questions:

How do clouds respond to changes in sea ice?

What is the surface radiative forcing due to sea ice-cloud interactions?



## Surface Layer

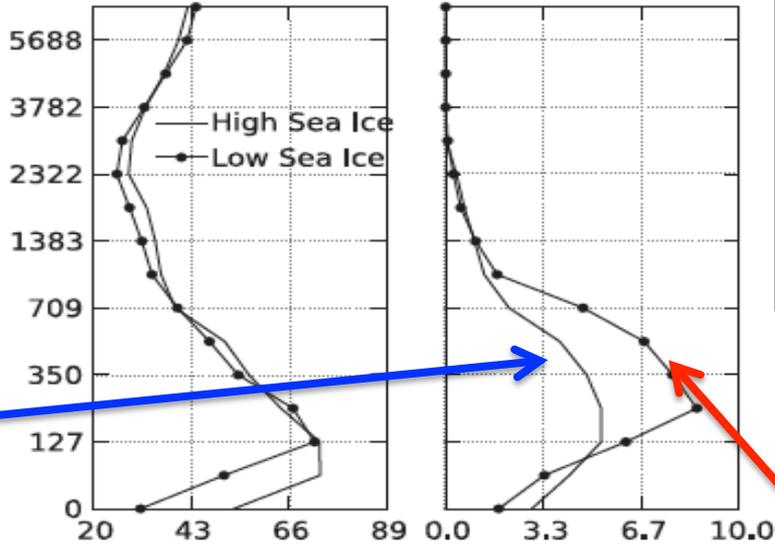
- Turbulence and  $q$  contributions can be weak or strong
- Sink of atmospheric moisture due to ice precipitation
- Surface type (ocean, ice, land) influences interaction with cloud

The influence of the surface type on the cloud properties implies an interaction between clouds and sea ice that may significantly influence Arctic climate change.

Morrison et al. (2012;  
Nature Geoscience)

# Sea ice-Cloud Interaction: Some Modeling Evidence

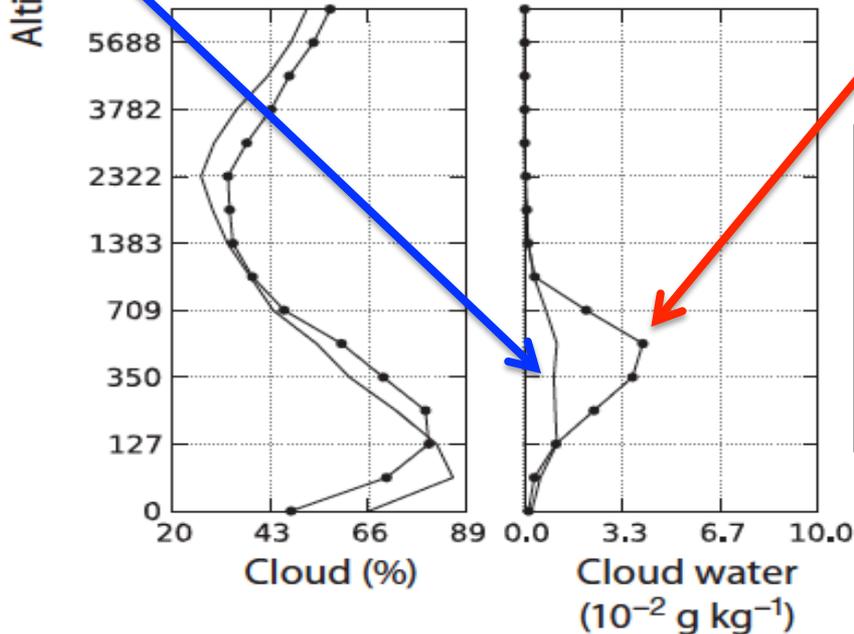
September



Cloud base and LWC are higher in Cloud Resolving Model simulations with anomalously low sea ice.

Barton and Veron (2012)

October



Surface radiative forcing due to sea ice-cloud interactions is only important during Oct. because SW and LW CRF offset in Sept.

High Sea Ice

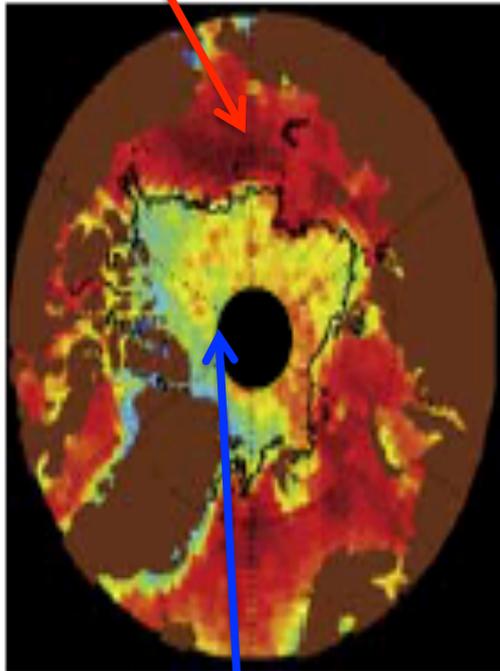
Low Sea Ice

# Sea ice-Cloud Interaction: Some Observational Evidence

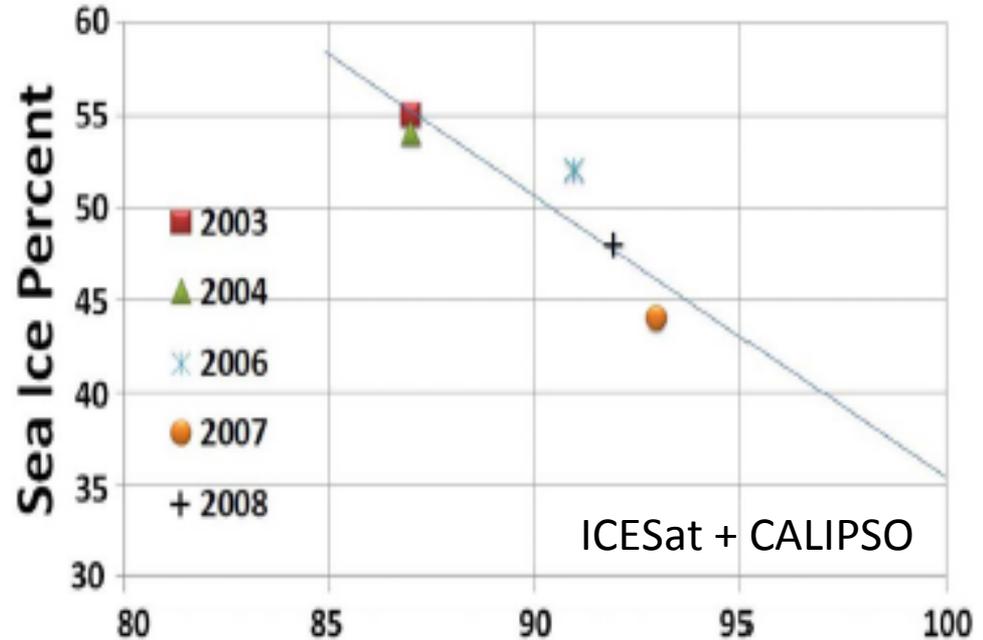
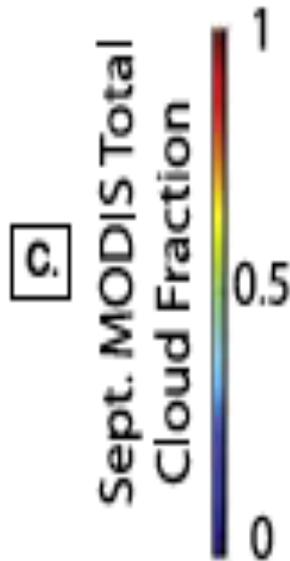
Significant correlation between cloud fraction and the sea ice extent in AUTUMN: larger cloud fraction over open water and lower cloud fraction over ice.

Larger cloud fraction over ocean

Kay and Gettelman (2009)



Sept. 2008

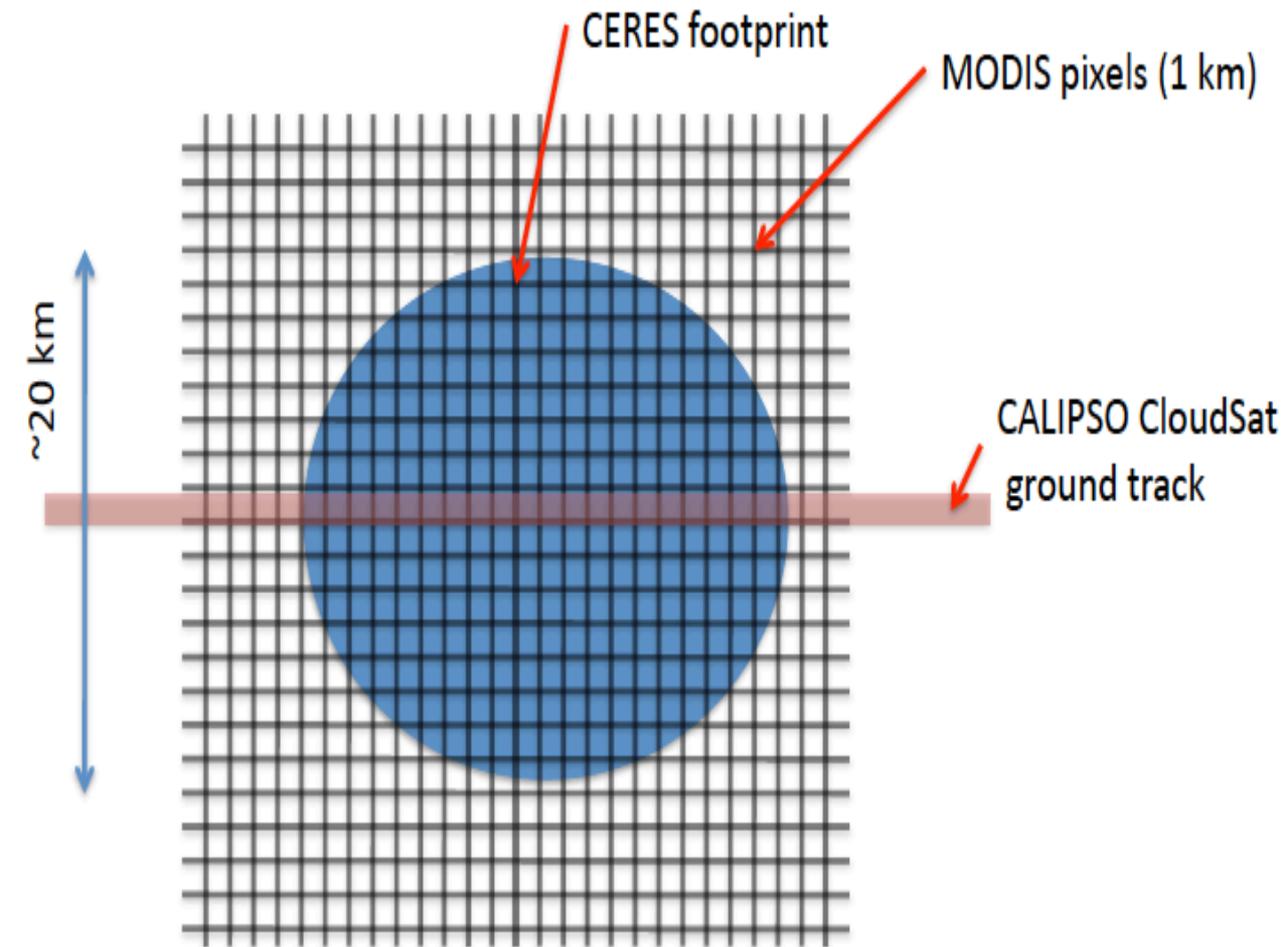


Palm et al. (2010) Cloud Percent

Lower cloud fraction over sea ice

No relationship during summer because the atmosphere and surface tend to be decoupled.

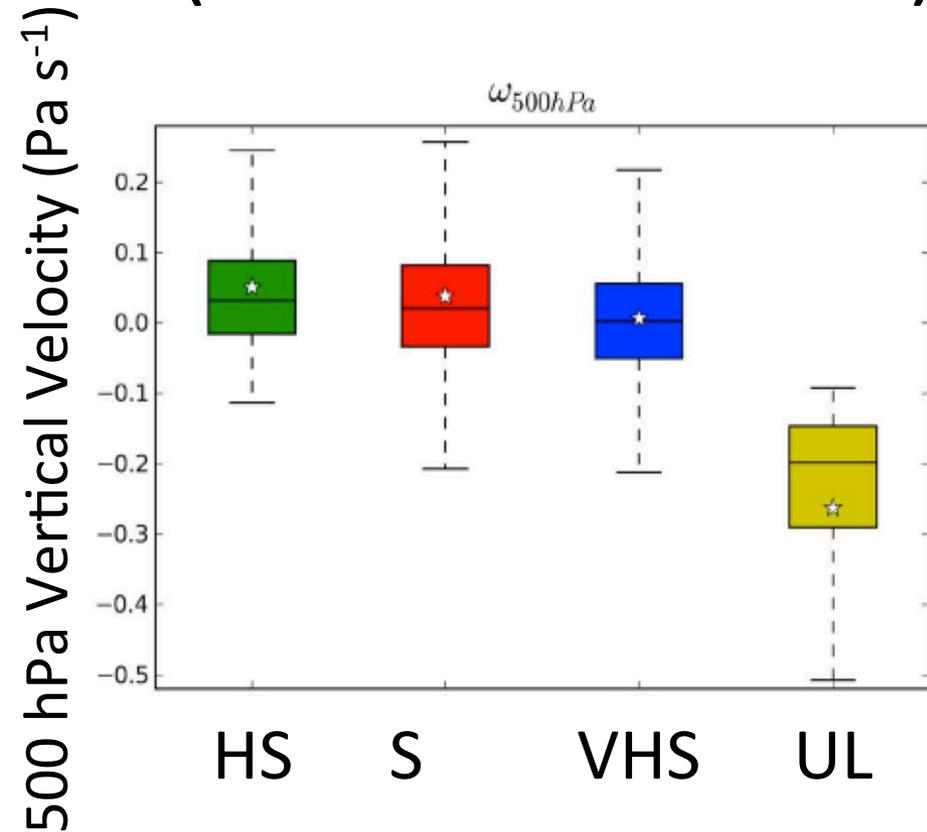
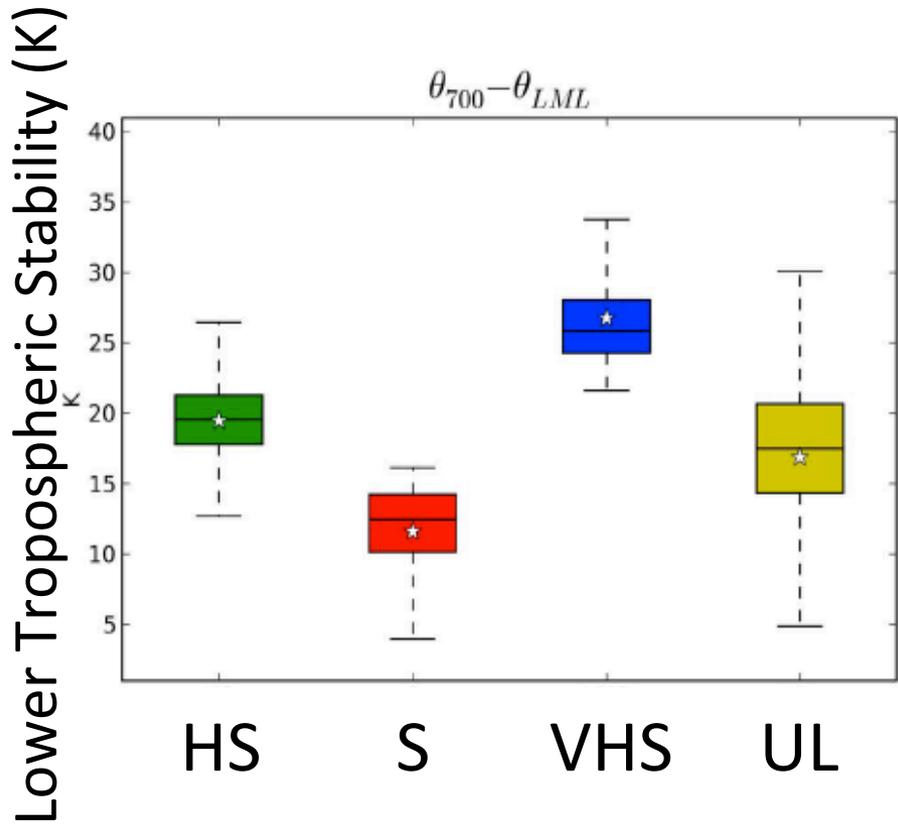
# CALIPSO-CloudSAT-CERES MODIS (C3M) Merged Data Product (Kato et al. 2010)



Data contains footprint averaged

1. Merged CALIPSO-CloudSAT vertical cloud property profiles (cloud fraction, LWC, IWC)
2. Computed vertical radiative flux profiles computed with CALIPSO and CloudSat derived cloud properties
3. Sea ice concentration (SSM/I)

# Atmospheric State Regimes (Barton et al. 2012)



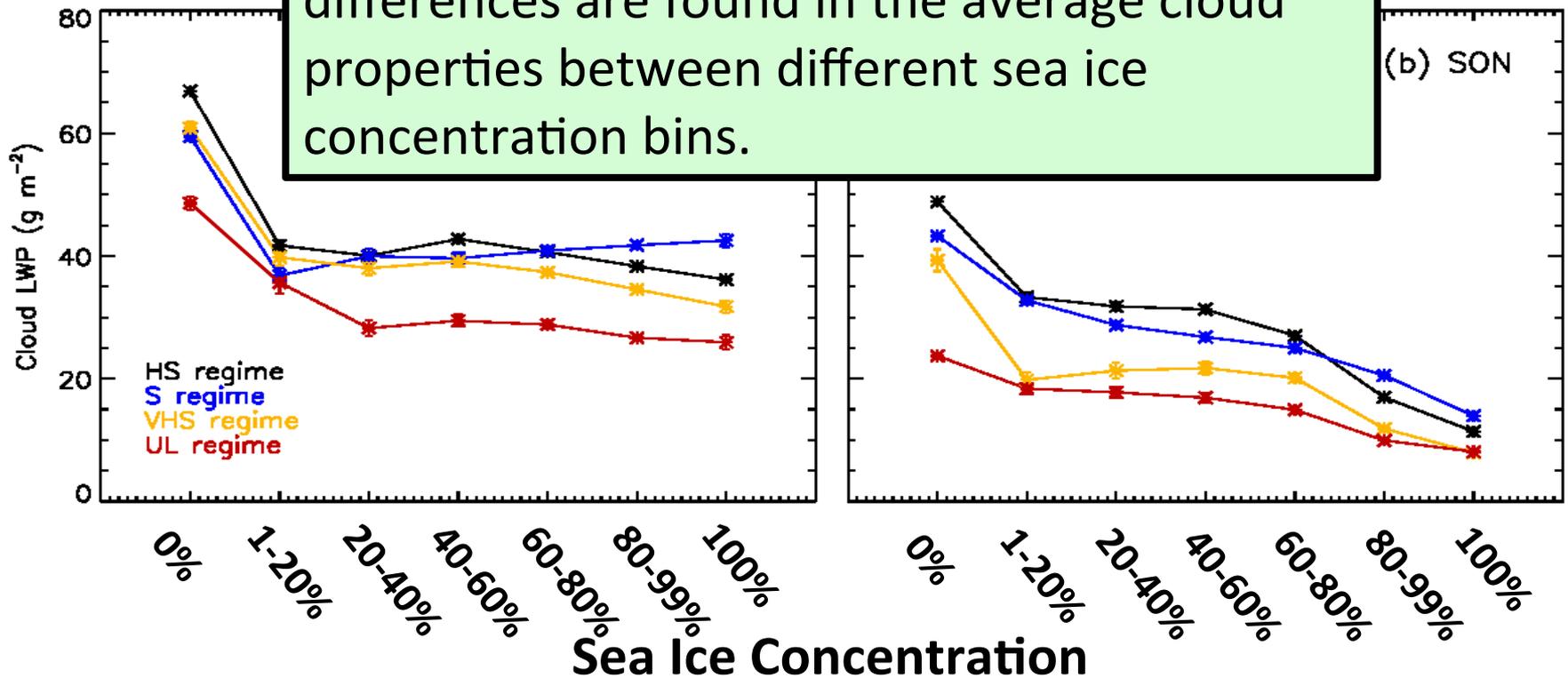
Atmospheric state regimes determined using K-means cluster analysis.

High Stability (HS):  $16 \text{ K} < \text{LTS} < 24 \text{ K}$   
Stable (S):  $\text{LTS} < 16 \text{ K}$   
Very High Stability (VHS):  $\text{LTS} > 24 \text{ K}$   
Uplift (UL):  $\omega_{500} < -0.1 \text{ Pa s}^{-1}$

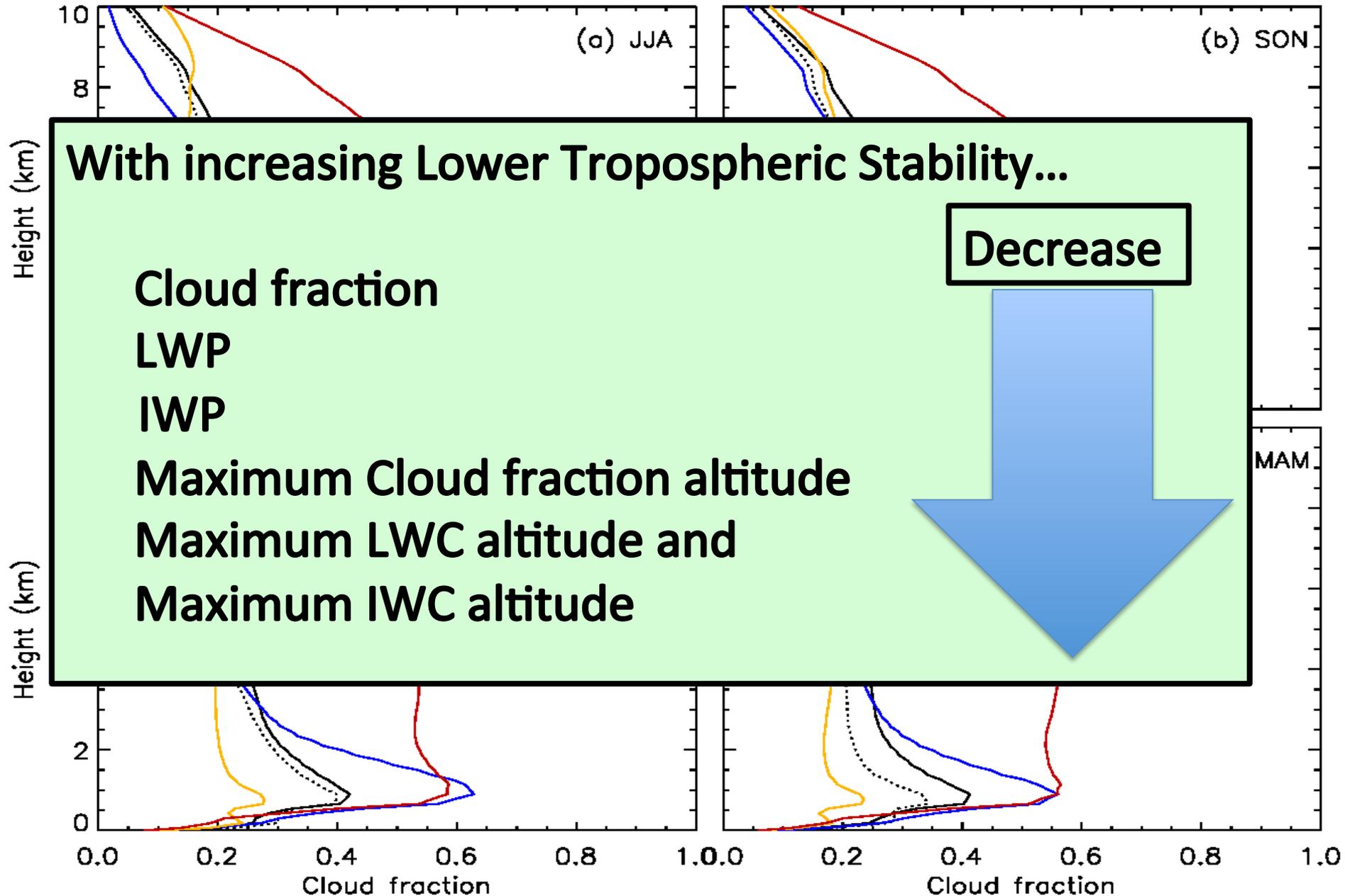
# Compositing Method...

- (1) Determine the Atmospheric Regime of each satellite footprint using MERRA
- (2) Determine the instantaneous sea ice concentration from SSM/I retrieval

A covariance between clouds and sea ice is said to occur if statistically significant differences are found in the average cloud properties between different sea ice concentration bins.



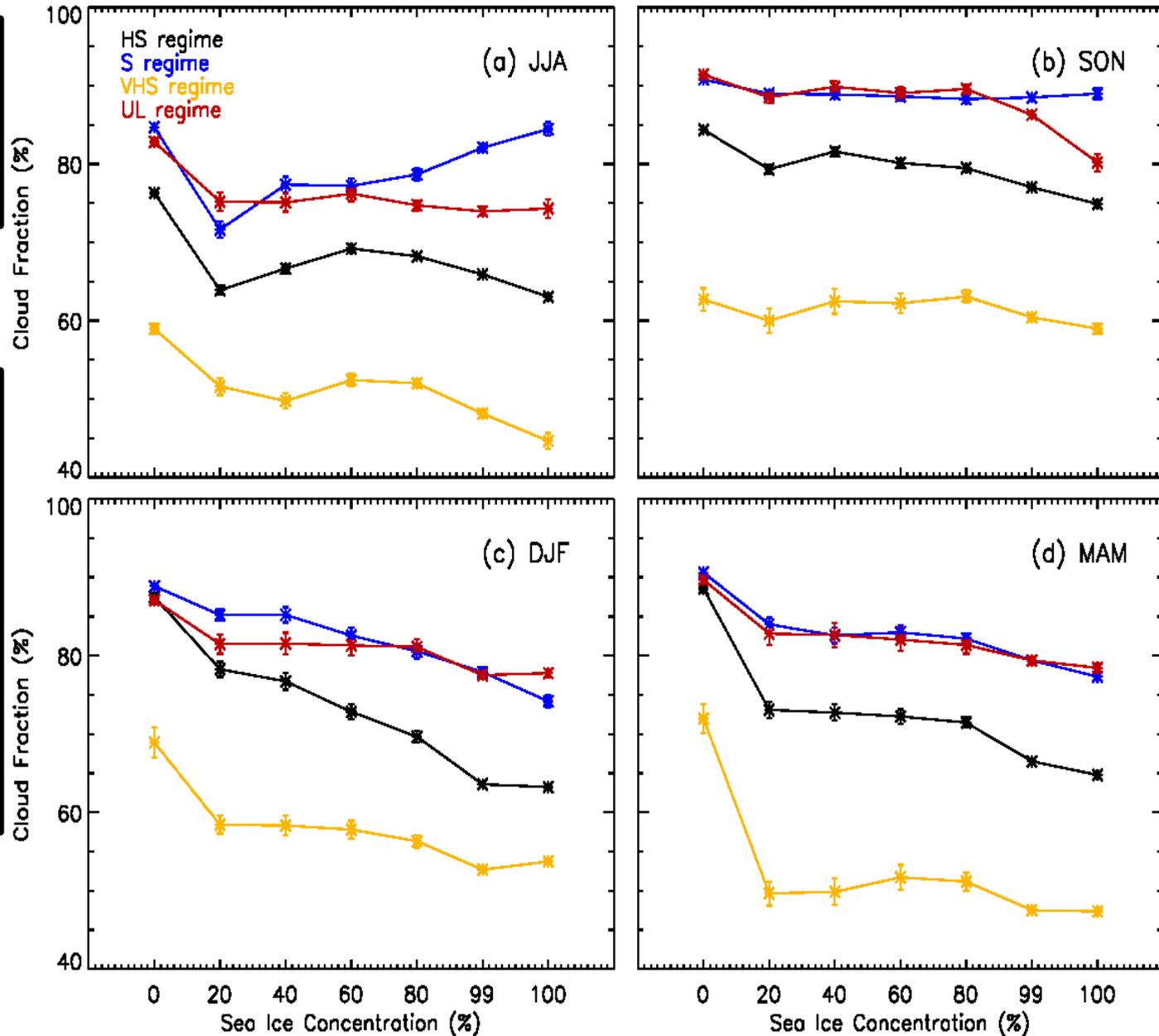
# Arctic Clouds and Meteorological State



# Low Cloud fraction vs. Sea ice Concentration

Cloud fraction decreases with increasing sea ice

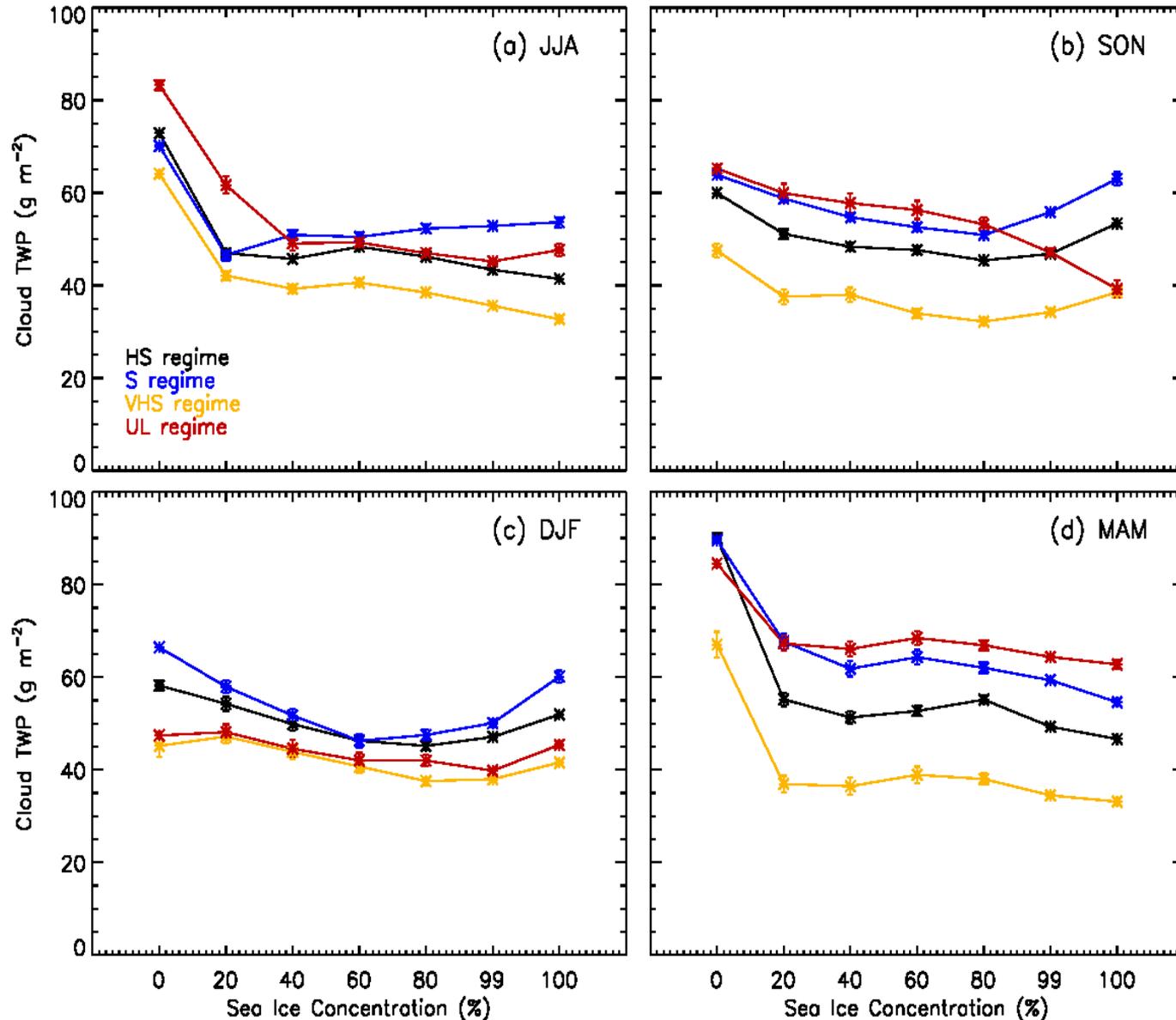
The magnitude of the cloud fraction change with sea ice varies with season and atmospheric regime.

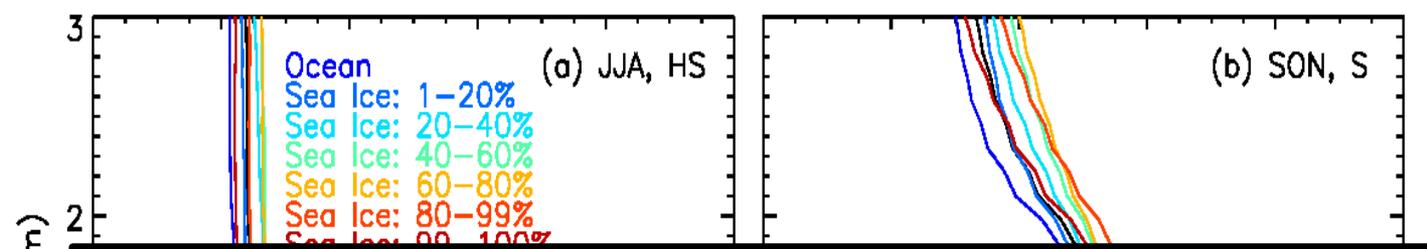


# Low Cloud TWP vs. Sea Ice Concentration

Cloud TWP decreases with increasing sea ice

The magnitude of the TWP change with sea ice varies with season and atmospheric regime.





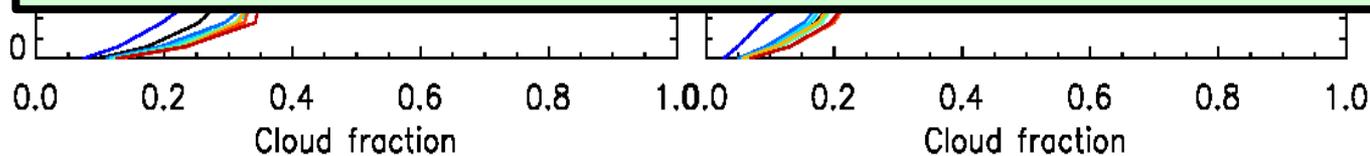
Cloud fraction vertical profiles are found to...

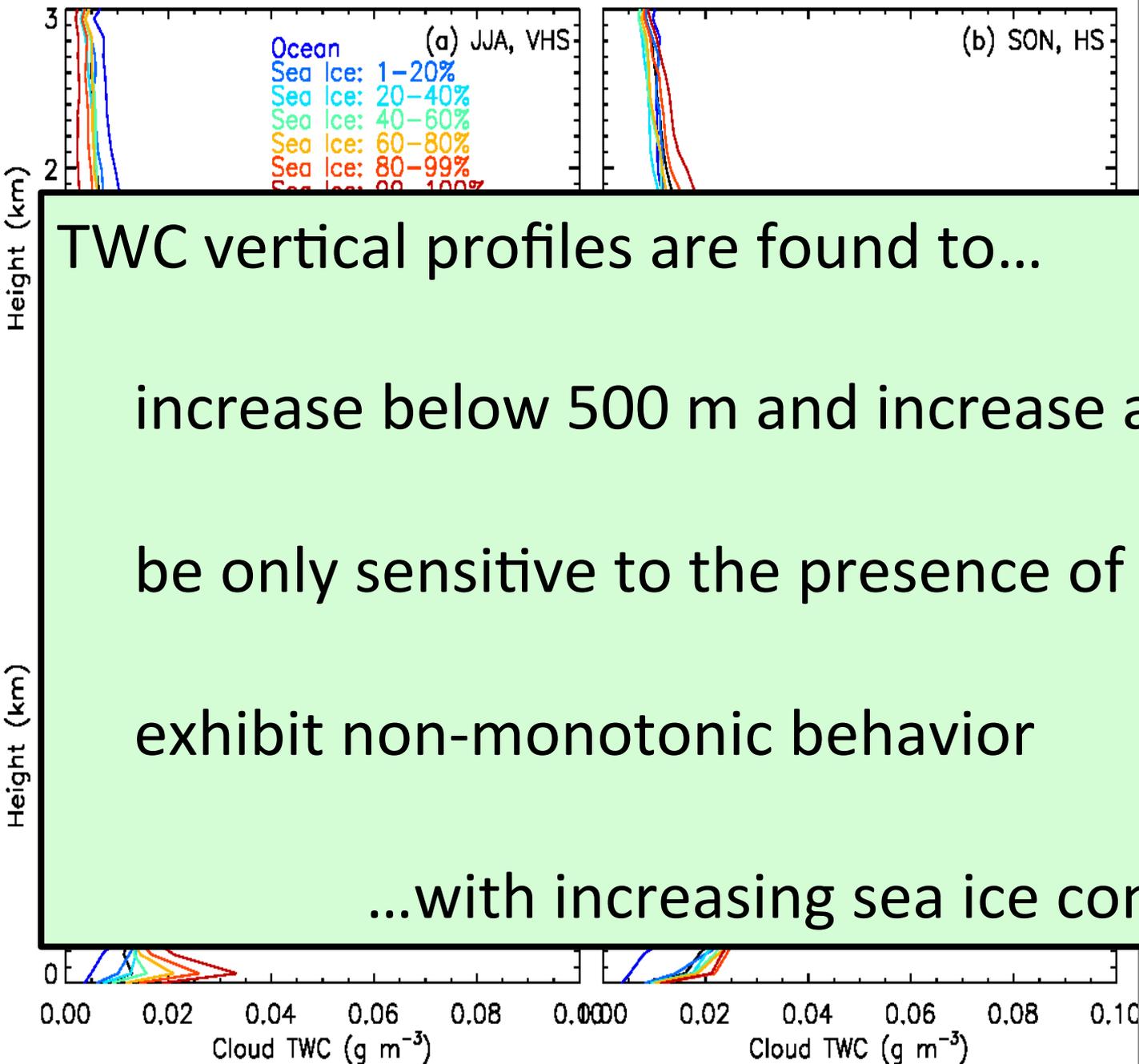
increase below 500 m and increase above 500m,

be only sensitive to the presence of sea ice, and

increase at all levels

...with increasing sea ice concentration.





TWC vertical profiles are found to...

increase below 500 m and increase above 500m,

be only sensitive to the presence of sea ice, and

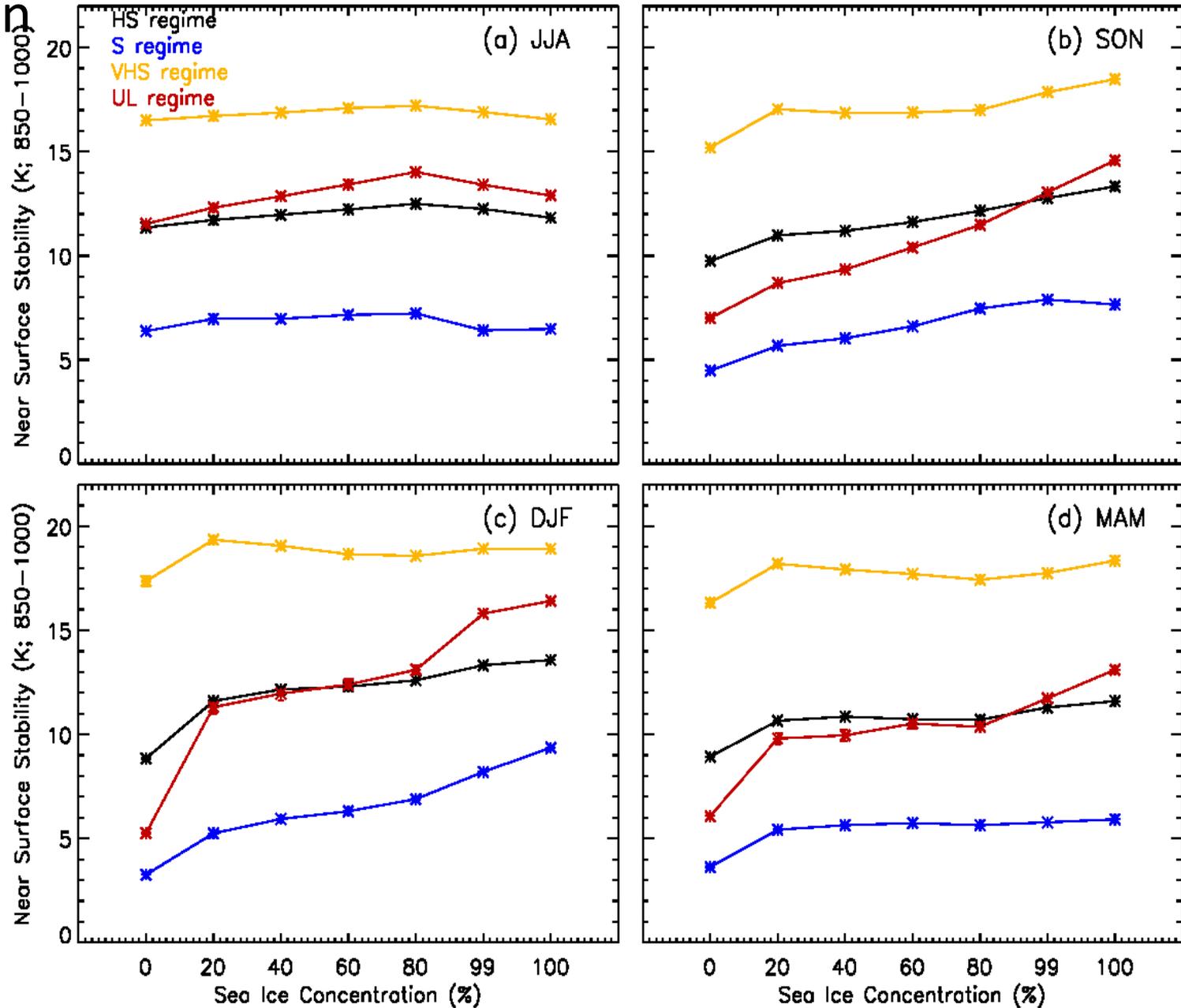
exhibit non-monotonic behavior

...with increasing sea ice concentration.

# Boundary Layer Temperature Structure and Sea Ice Concentration

Higher LTS is associated with higher near surface stability.

Near surface stability increase with increased sea ice



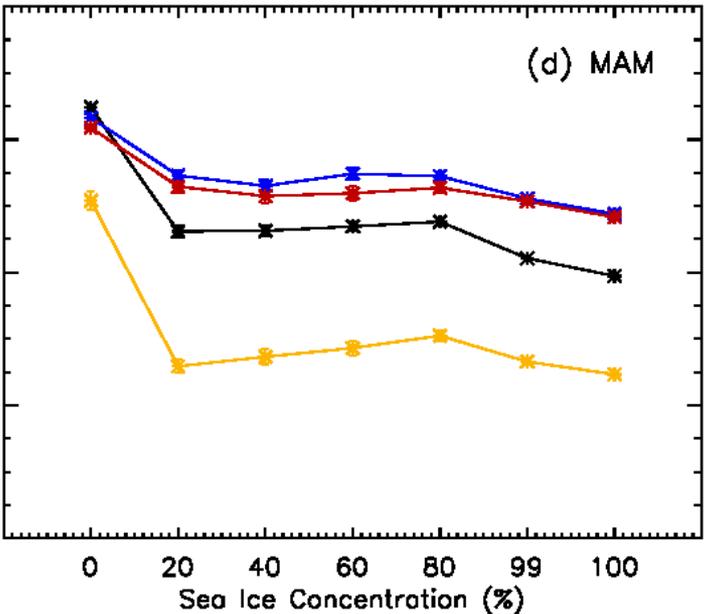
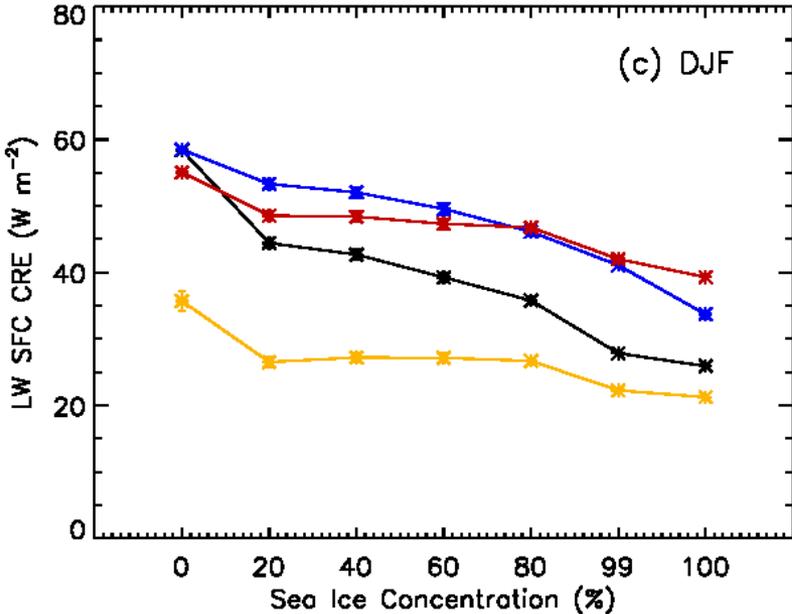
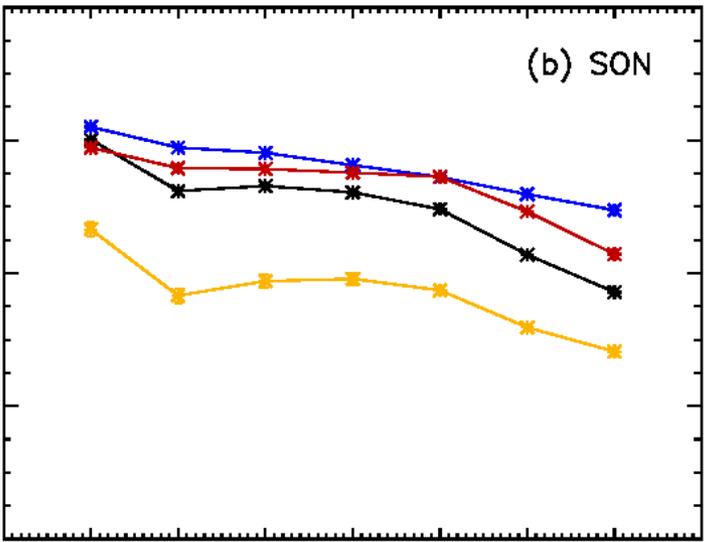
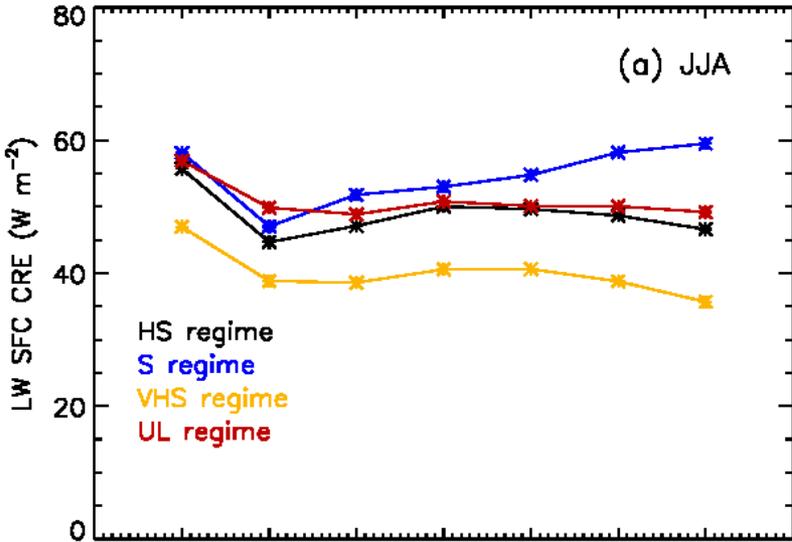
# CRE vs. Sea ice Concentration

$$\text{LW\_CRE} = \text{LWdn\_all} - \text{LWdn\_clr}$$

$$\text{SW\_CRE} = \text{SWdn\_all} - \text{SWdn\_clr} * (1 - \alpha)$$

$$\text{Net\_CRE} = \text{SW\_CRE} + \text{LW\_CRE}$$

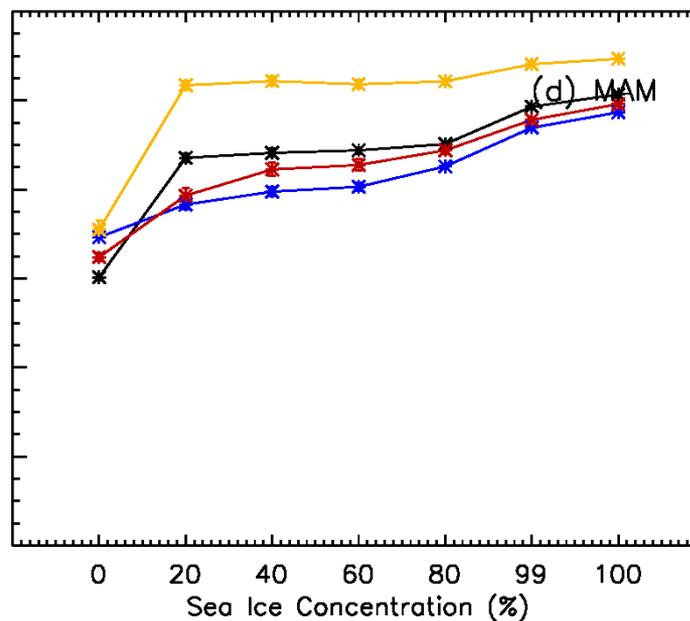
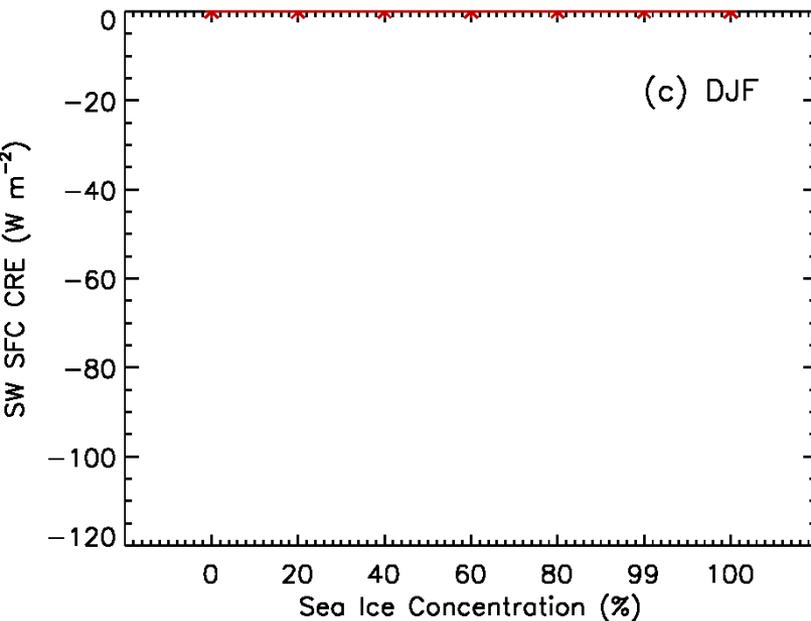
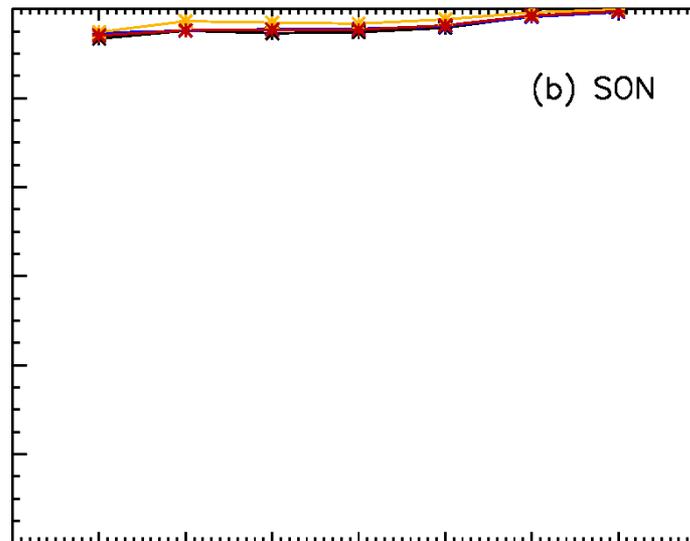
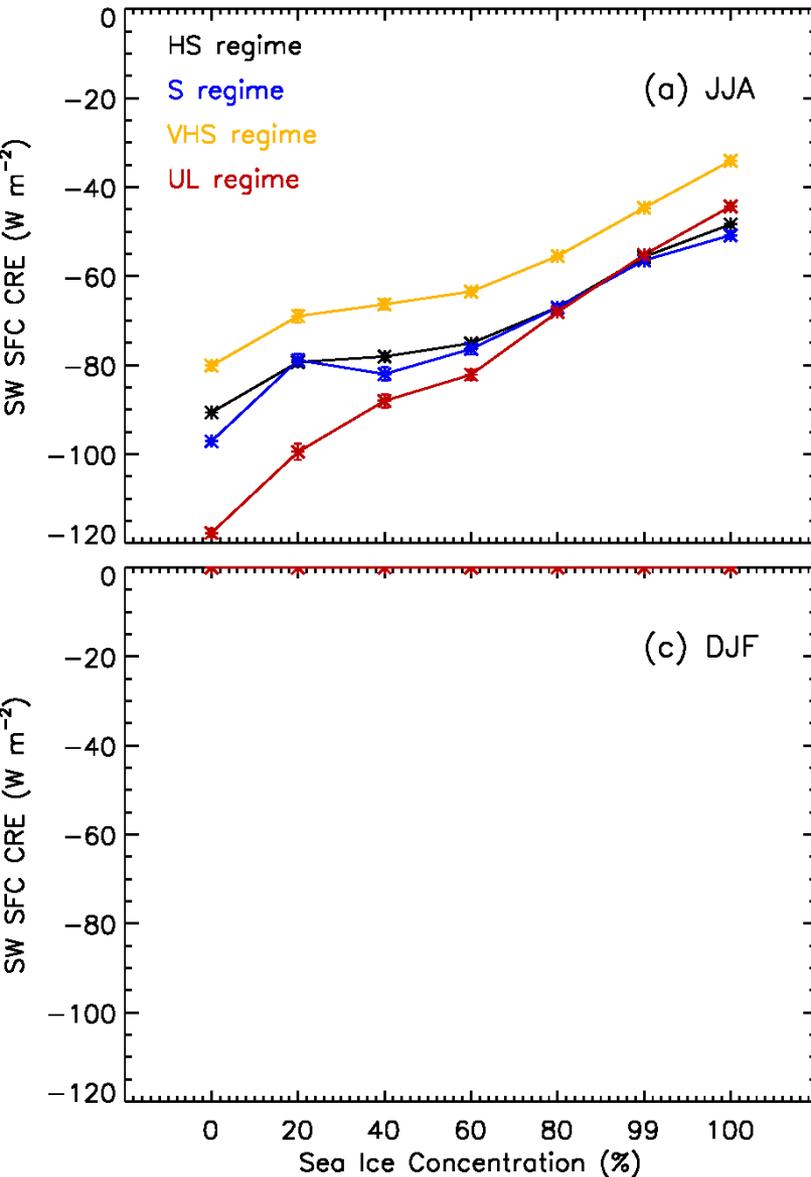
# LW Surface Cloud Radiative Effect and Sea Ice Concentration



LW CRE is positive in all seasons.

LW CRE tends to decrease with increased sea ice.

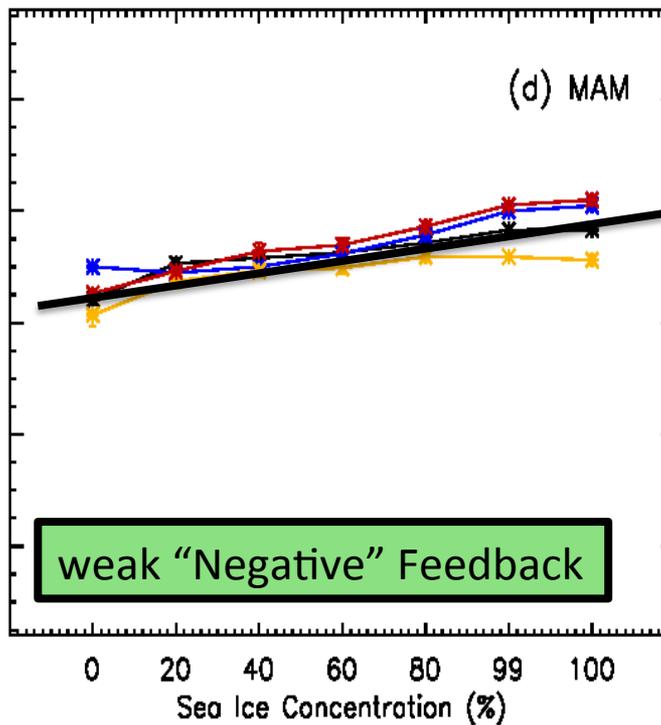
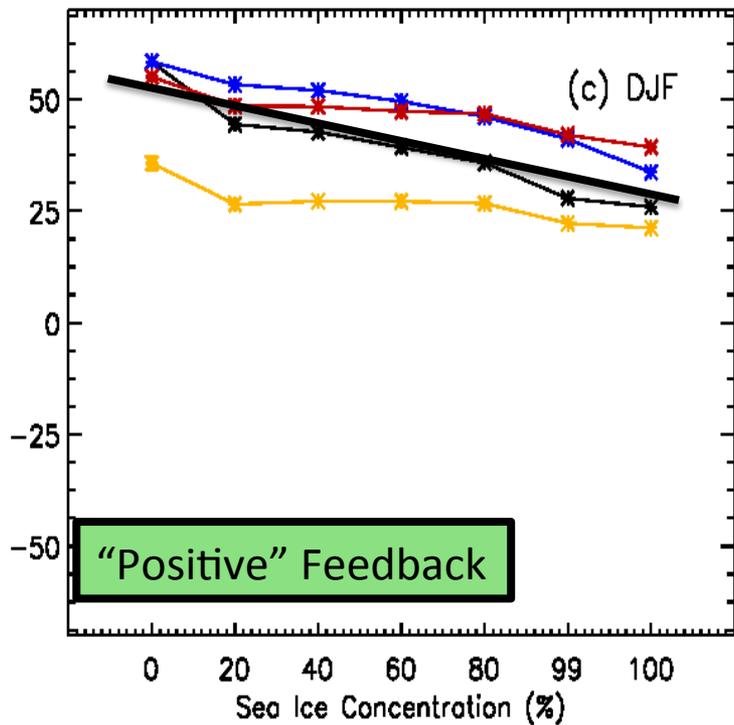
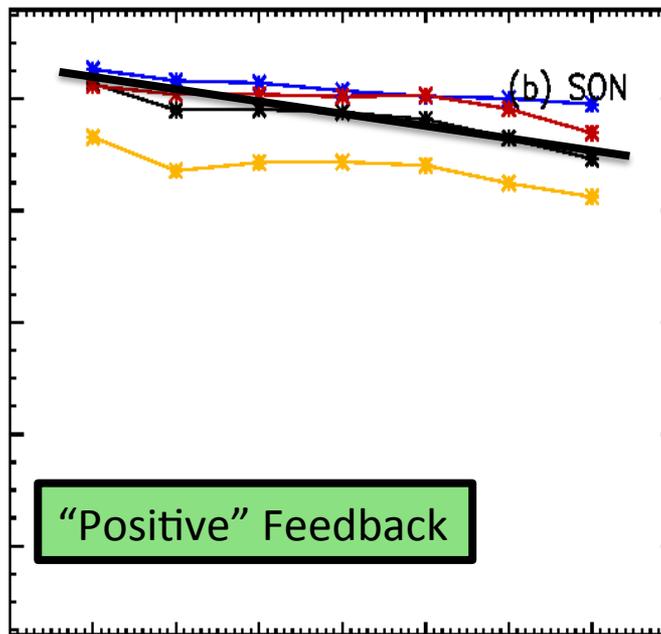
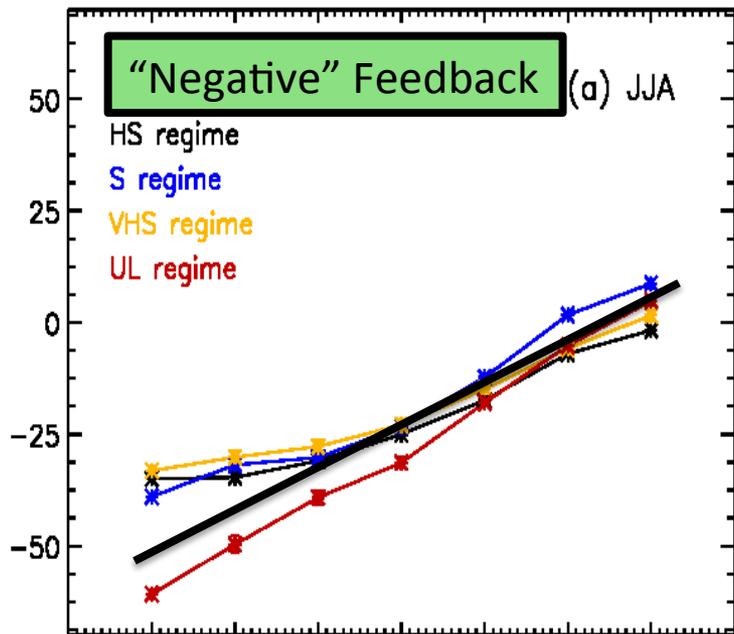
# SW Surface Cloud Radiative Effect and Sea Ice Concentration



SW CRE is negative in all seasons.

SW CRE tends to decrease with increased sea ice.

Net Cloud Radiative Forcing ( $W m^{-2}$ )

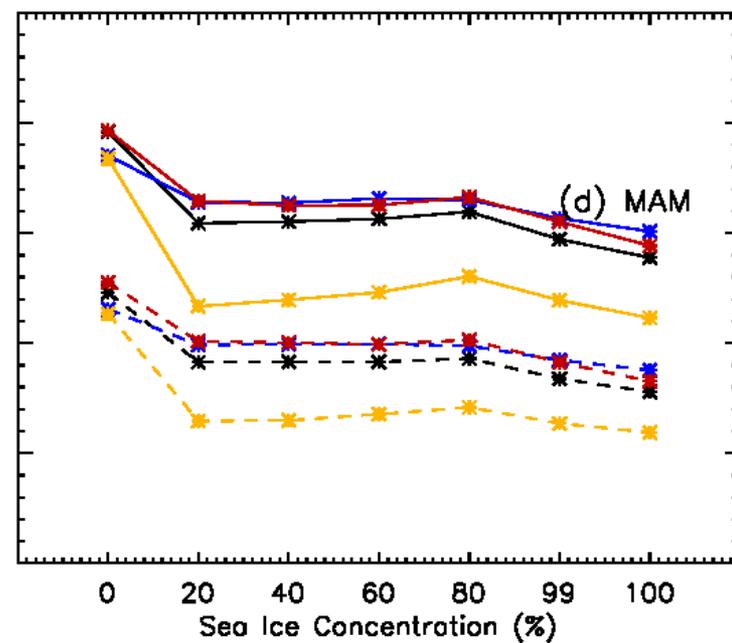
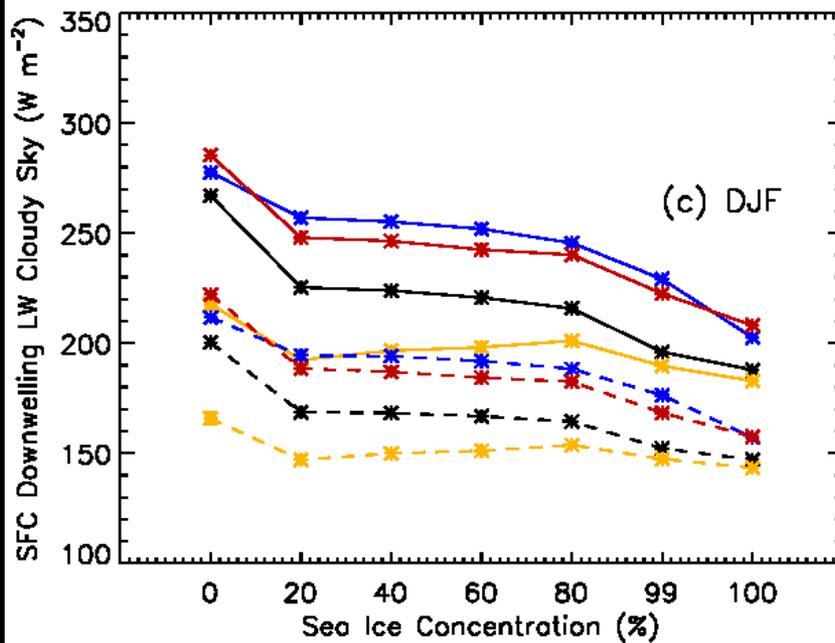
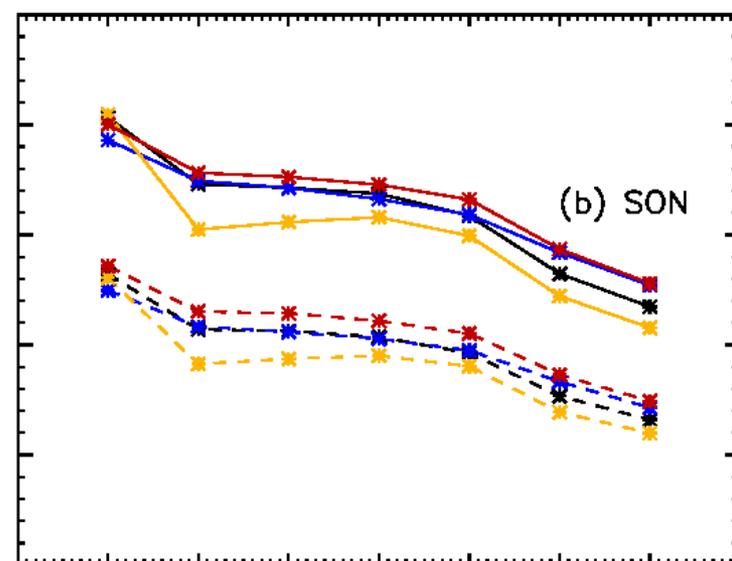
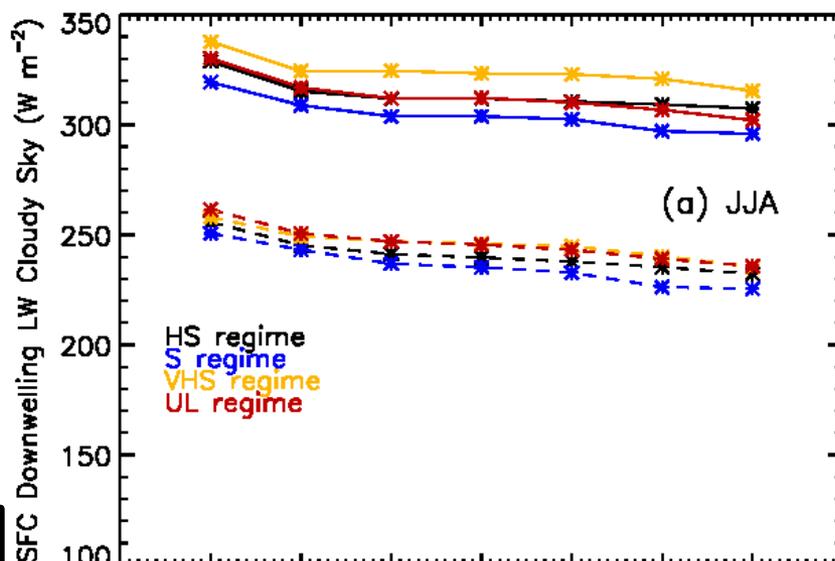


Net CRE  
vs.  
sea ice

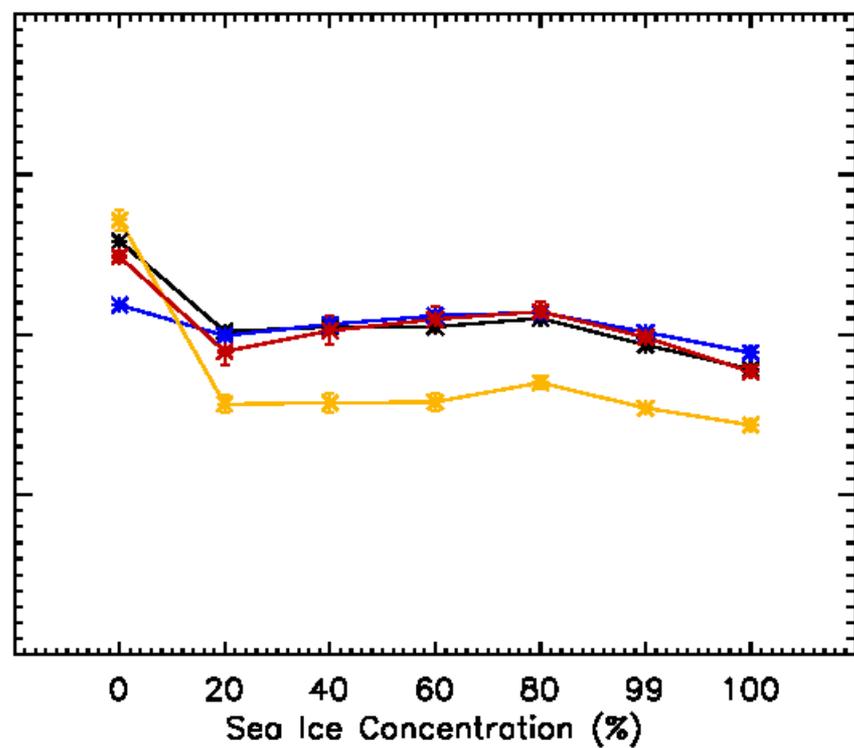
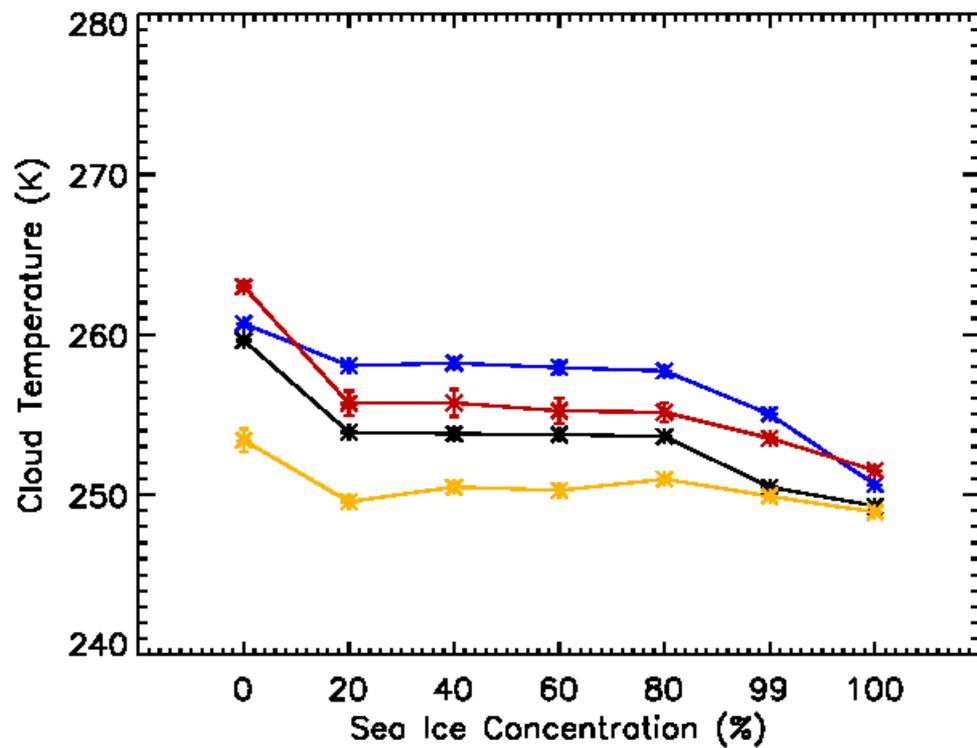
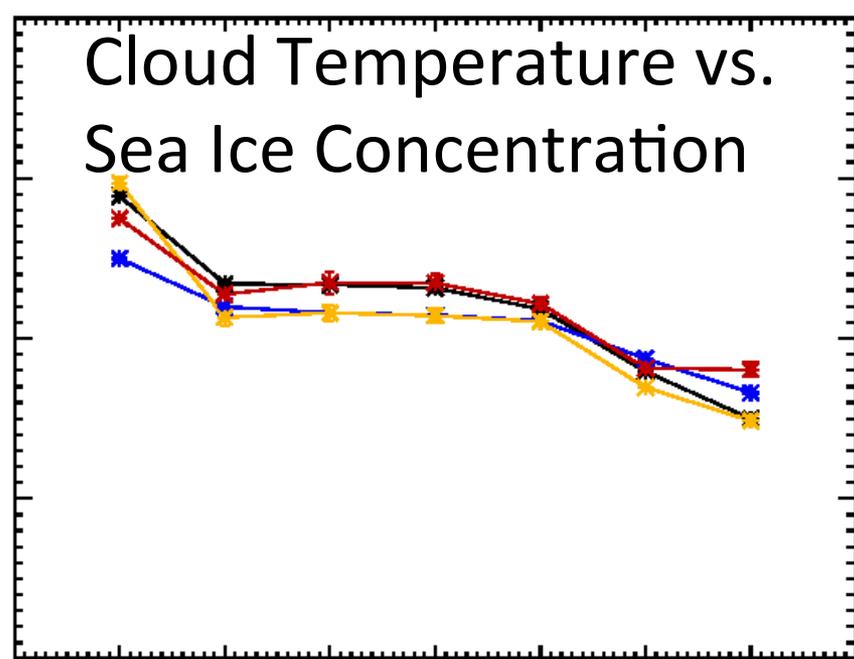
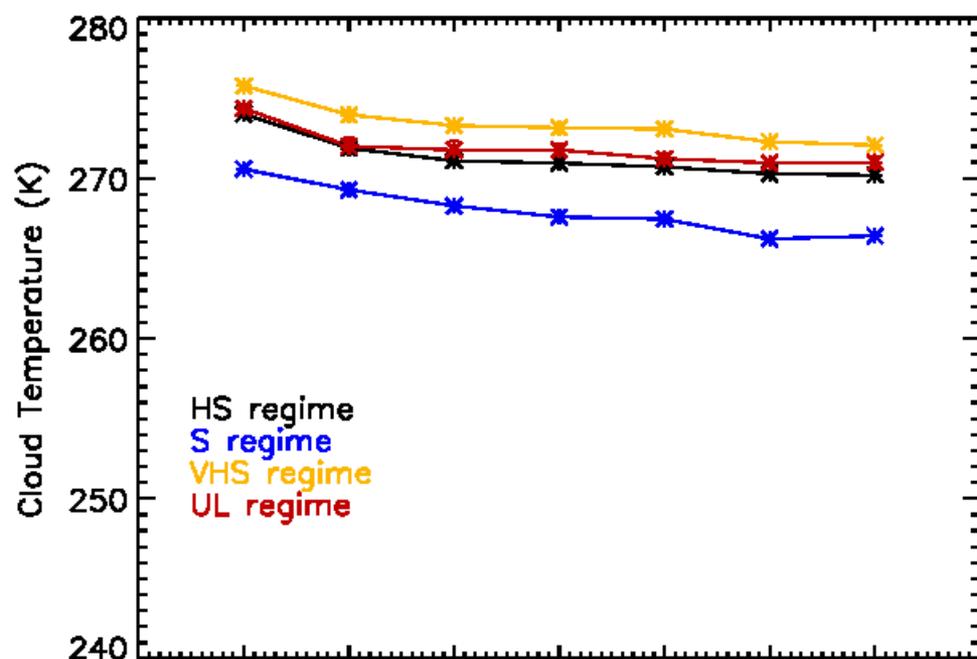
# Decomposition using independent column approx.: Longwave

$$LW\_all=(1-N)*F\_clr+N*F\_cld$$

Longwave



Both the clear-sky and cloudy sky fluxes decrease with increased sea ice.



# Summary and Conclusion

-Arctic low cloud properties are sensitive to the atmospheric conditions: Cloud fraction, LWP, and IWP decrease with increased stability.

-A statistically significant covariance between Arctic cloud properties and sea ice concentration are found in each regime and season: Cloud fraction, LWP, and TWP decrease with increased sea ice concentration.

-Covariance between Arctic low cloud properties and sea ice concentration are also found to significantly influence the surface energy budget.

“Negative Feedback” in Summer (SW CRE dominates)

“Positive Feedback” in Fall and Winter (LW CRE dominates)

Questions?



# Zonal mean Surface Temperature Response (1% per year CO<sub>2</sub> increase)

